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THE BINOCULAR MICROSCOPE AND STEREOSCOPIC VISION.

By GEO. E. FELL, Buffalo, N. Y.

In presenting to the Society at this session a consideration of the subject which forms the title of this paper, I may briefly detail my reasons for so doing. I am well aware it has been satisfactorily discussed heretofore, and as a result we have, scattered here and there through various scientific periodicals, a number of interesting and valuable papers pertaining to it. Of these, however, many are not readily accessible to the majority of our members, which may possibly account for the fact that a large percentage of our microscopists are not, apparently, conversant with the principles upon which the various forms of binocular microscopes are constructed. Many question whether a stereoscopic effect is produced by the so-termed binoculars; while others, who exclusively use the monocular form of instrument, are disinclined to accord *any good whatever* to the binocular arrangements.

In the course of a controversy regarding this subject, which took place some months ago, several otherwise well-informed microscopists assumed the following grounds:

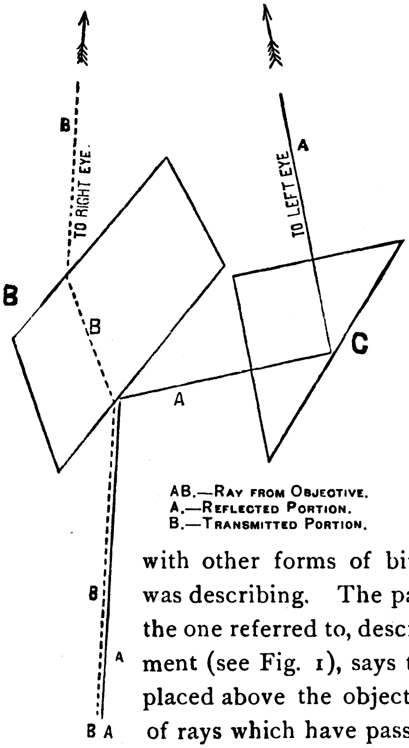
First.—No particular advantage is obtained or derived from the use of the binocular, over the monocular form of instrument.

Second.—No *true* stereoscopic effect is produced in the ordinary form of binocular arrangement; such apparent effect being the result of an optical illusion, which is enhanced by a difference in the illumination of the two fields.

These two assumptions will serve to present the negative side of the controversy which we are about to engage in, and furnish, in my opinion, sufficient grounds for a further consideration of the subject.

Fig. 1.

Powell & Lealand Binocular.



AB.—Ray from Objective.
A.—Reflected Portion.
B.—Transmitted Portion.

Among the arguments put forth in support of that portion of the *second* assertion relating to stereoscopic effect, was a quotation from Dr. L. S. Beale, which, unless analyzed, is apt to mislead the general reader.* "The last of the two images is less intense, but still it is light enough to be seen very clearly. The two images thus formed are exactly similar, and the two pictures appear to the observer as one, and in relief. There is, however, *no true stereoscopic image*, for the one picture seems to be in every respect, save in intensity of illumination, the counterpart of the other." This quotation was presented as embodying the views entertained by Dr. Beale, on the subject of stereoscopic effect produced by the binocular microscope. On reference to the context, however, we ascertain that the paragraph in question was intended to apply to the binocular arrangement for high powers, devised by Messrs. Powell & Lealand, and which, in connection with other forms of binocular microscopes, Dr. Beale was describing. The paragraph immediately preceding the one referred to, describing the action of this arrangement (see Fig. 1), says that the prisms employed "are placed above the object glasses." Of the total number of rays which have passed through the object glass, the greater part are transmitted through the prism (B) and the straight tube of the microscope; but some suffer reflection from its lowest surface and are received upon the reflecting surface of the prism (C) in an oblique direction, as shown by the lines (A A) and after emerging from the surface, enter the diagonal tube of the microscope." From this description it is seen that two different images cannot be formed by this arrangement of prisms. The *complete bundle* of rays proceeding from the posterior combination of the objective, being received upon the prism (B), each ray is split (doubly refracted) into a reflected and transmitted beam. The former pass into the prism (C) and thence into the diagonal tube of the microscope, while the latter are transmitted through the prism (B) and form the second image; consequently the images being similar, except as regards the illumination, there can be no true stereoscopic effect produced. Dr. Carpenter calls this arrangement Powell & Lealand's *non-stereoscopic* binocular.*

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* How to Work with the Microscope, page 11.

Regarding similar arrangements for high powers, of which there are a number with slight modifications, Mr. F. H. Wenham says: † "As to the performance of the arrangement, the introduction of the prisms does not perceptibly interfere with the definition in the direct tube, and having the privilege *of using both eyes*, the observer is enabled to view minute objects more agreeably, and with a better idea of their structure than with single vision. The great defect is a want of *stereoscopic* effect arising from the near similarity of the images. In this respect it falls far short of the common prism in the qualification of giving a perspective view with the low powers."

From these statements it appears that the Powell & Lealand form of instrument, or prism arrangement, does not, or really was not intended to produce a stereoscopic effect.

Another argument advanced, as opposed to the production of the *true* stereoscopic effect by the binocular microscope, was as follows: "In the use of one objective and ocular (or even two oculars), but one image can be produced, or at the best, two, which in outline are similar, and therefore not capable of producing a stereoscopic effect." We will consider these views in due season.

It is not alone in the stereoscopic effect produced, however, that the binocular form of instrument is to be recommended. There are other substantial arguments in favor of its use within *its range of adaptability.*

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* The Microscope and its Revelations, 5th ed., p. 111.
† Transaction London Society, Vol. xiv., p. 106.

President F. A. P. Barnard, of Columbia College, in a paper read August, 1870, before the "American Association for the Advancement of Science," says, in referring to the non-stereoscopic binocular: "They have not the advantage which belongs to stereotomic (stereoscopic) binoculars, of presenting the object viewed in all its three dimensions. But they permit what most observers regard as very desirable, or find at least very comfortable, the use of both eyes at the same time. It is true that there are many whom practice has so accustomed to the use of a single eye, that they profess to suffer no inconvenience from this mode of observation, and regard binoculars with indifference, except so far as they are recommended by their stereoscopic effect. But however slight may be the momentary inconvenience attendant on observation with a single eye, it is believed that no microscopist can continue to observe in this manner for a series of years (I will say for a short period of time), without finding that his eyes have lost the equal power which they once possessed of accommodating themselves to distances. It seems impossible to prevent this result from supervening, sooner or later, unless by maintaining a strict impartiality in the employment of the eyes alternately at the microscope; and this is what few remember, or if they remember, are disposed to do. If by the use of a binocular this evil can be prevented, this fact alone is sufficient to make a good form of this instrument, adapted to the higher powers (or even lower), desirable."

Dr. W. B. Carpenter gives his evidence regarding the benefit derived from the use of the Powell & Lealand binocular arrangement in the following terms, in which he states that he "*Can bear the most explicit testimony to the diminution of fatigue resulting from the use of this little apparatus, by which a prolonged employment of high powers is permitted, that would be prejudicial to the eye used singly; whilst it entirely prevents that bad effect which is liable to proceed from the too exclusive use of a single eye,—the impairment of its power of focusing consentaneously with the other eye in ordinary vision." To all other forms of binocular microscope, where definition is at all satisfactory, the same advantage must be accorded, while in the true stereoscopic arrangements this very desirable qualification must be included with that of security and safety to the eyesight.

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* The Microscope and its Revelations, 5th ed., p. 111.

It has, however, as previously stated, been questioned by many prominent workers with the microscope, whether, in the present form of binocular arrangement, we have a true stereoscopic effect produced. To attain such an effect it will generally be admitted that two dissimilar pictures of an object, such as may be produced by a slight (lateral) variation in the point of view from which they are taken or viewed, are requisite. We will not assume, nor do we believe, the statement made by a writer in the November, 1880, number of the American Monthly Microscopic Journal, that it is owing greatly to the difference of the brightness of the two images that the stereoscopic effect is produced. As he says: "Experience has shown that the production of a good stereoscopic effect requires one perfect and clear picture, beside which, the other may, without noticeable detriment, be far less perfect; and it is to be presumed the same result may follow any difference in brightness." It might as reasonably be stated that in natural vision our stereoscopic view of objects would be enhanced by a slight opacity of the cornea of one eye, whereas the other should be perfectly reliable. Who may be responsible for this statement or view, originally, I cannot say, but it appears to be founded on erroneous views, as it virtually implies that an individual with one normal and one defective eye can see better than one with a normal pair. The cases appear quite parallel, and in my observation I have never seen an instance in which two unequally illuminated stereoscopic pictures gave as good a stereoscopic effect as when both were brightly and equally illuminated. I believe this will apply to the images produced in the stereoscopic binocular microscope.

In the ordinary form of stereoscopic binocular microscope, among which may be mentioned the Wenham (Fig. 4), Tolles (binocular eye-piece), (Fig. 5), the Stephenson, or rather Riddle arrangement, and Nachet Stereoscopic and Pseudoscopic forms, we depend for the stereoscopic effect upon the production of two different images, which, combined, have all the requisites necessary to the formation of a true stereoscopic image, resulting (to the normal *eyes*) in an appearance of solidity approximating to that observed in natural vision, or in the examination of views properly prepared and arranged for the stereoscope.

The construction of the stereoscopic binocular is based upon the fact that the rays proceeding from the two lateral halves of the objective produce *slightly different* images, and in the arrangement of the prisms of most of these instruments, the cone of rays proceeding from the posterior combination of the objective is so divided that the image produced by each lateral half is sent, one to the right and the other to the left eye of the observer. Prof. J. L. Riddle, of the University of New Orleans, first devised an instrument of this character in which a division of the cone of rays proceeding from the objective was effected. He is, therefore, entitled to whatever credit may be due for thus originating the stereoscopic binocular microscope.

That there is a very noticeable difference in the images formed by the respective tubes of the stereoscopic binocular microscope, we will not contend. However, with the ordinary Wenham binocular, they may be easily demonstrated to an unprejudiced observer, at least sufficiently well to place beyond cavil the question of variation in the outline of the two images.

On an ordinary glass slip I cemented a minute cubical piece of glass, broken from a thin glass cover. The edge of this piece of glass presented dissimilar appearances when viewed through the different tübes of a (properly constructed) *Wenham binocular, with a low-angled, ½ inch objective, the object being in the center of the field, or in the same position on the stage of the microscope during both observations. The difference in appearance of the two images is just what might be expected in viewing an object from two slightly varying points of vision. Any other combination of objectives and oculars (preferably below the ½ inch objective), with an object having an appreciable thickness, will answer in demonstrating the differences of the images with this form of instrument. Furthermore, we have competent authority to prove that if photographs be taken of the images produced by the lateral halves of the monocular microscope, and these photographs be mounted for observation by the stereoscope, that a stereoscopic effect, or appearance of relief and solidity, will be presented to the observer.

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* I have seen binoculars constructed on the Wenham plan, in which, owing to a defective prism, or bad setting, it was impossible with them to obtain satisfactory results.

Mr. F. H. Wenham, in an article on micro-stereographs says: "*Some remarks have been published on the possibility of obtaining stereoscopic pictures of microscopic objects by means of the binocular microscope; but the ordinary instrument (the *monocular*) will answer every purpose, without any optical addition whatever, for it has been shown (by Prof. Riddle) that if the object itself be viewed alternately with the right and left half of the object glass, without any altering of its position, the difference in form of the resulting images assimilates to the effect of a different angle of vision; and if two photographs of the object obtained by the separate halves of the object glass, be placed in the stereoscope, they will give an appearance of solidity to the object. The only addition that is required to produce this effect, is to fix a sliding stop close behind the objective, having straight edges that will cut either the right- or left-hand sides. A photographic impression being taken at the two extremes."

Mr. Wenham illustrated† this difference by making, on another occasion, enlarged drawings of the egg of the common bed-bug (*cimex lecticularius*), with the right and left halves of the object-glass alternately stopped off. A noticeable difference in the figures was the result. With the eye-piece also a similar result was obtained. He states: "If this experiment be repeated by holding the card over the eye-piece and stopping off alternately the right and left half of the ultimate emergent pencil, exactly the same changes and appearances will be observed in the object under view. The two different images produced are such as are required for obtaining stereoscopic vision."

From these statements it appears that even in the compound *monocular microscope* we have all the requisites to the formation of two images, which, if separated and brought, the proper one to the right and the other to the left eye of the observer, will, without question, produce a stereoscopic effect.

It is precisely this that the stereoscopic binocular accomplishes. We must note, however, that the monocular instrument, as ordinarily constructed, reverses the picture; and consequently to receive the stereoscopic effect, the rays from the right and left half of the objective must be made to pass to the left and right eyes, respectively, of the observer. In the stereoscopic binocular, this condition is fulfilled by numerous ingenious methods of arranging the prism or prisms which divide the cone of rays proceeding from the posterior combination of the objective.

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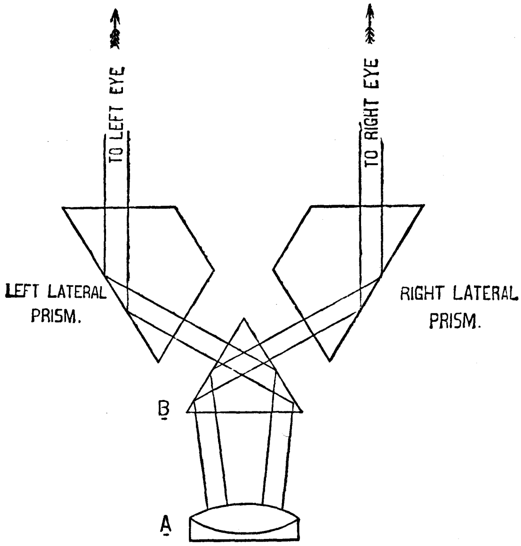
* Transaction London Society, Vol. iii., N. S., p. 5.

† Transaction London Sobiety, Vol ii., N. S., p. 4.

With these remarks we can now look into the construction of the different forms of stereoscopic binoculars, and note the manner in which this division of the cone of rays is affected.

Fig. 2.

Nachet Stereoscopic Binocular.

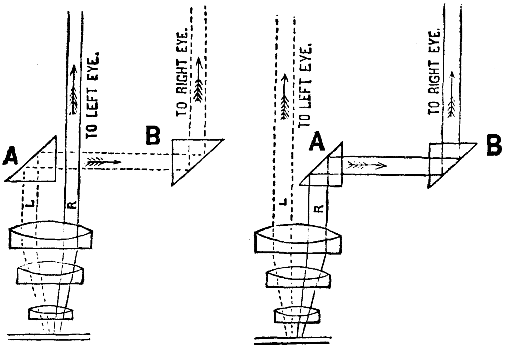


One of the earlier forms, the Nachet binocular, is represented at Fig. 2. The rays proceeding from the objective (A) are received by the flat surface of the triangular prism (B), and entering into it, suffer total reflection from the oblique surfaces which equally divide the cone of rays and sends them in opposite directions. They then pass out from the upper surface of the triangular prism at right angles, or normal to its surface, and each separate half of the original cone of rays is received upon its respective lateral prism into which it enters, and being again internally reflected in the proper directions, pass again normally from the upper surfaces of the lateral prisms to their respective eye-pieces. For some purposes, it is stated, this arrangement works well, but owing to the loss of light occasioned by the numerous reflections and number of surfaces through which each series of rays must pass before reaching the eyes, coupled with the fact that it can not be used as a monocular, it has not come into general use.

The Natchet Stereo-pseudoscopic arrangement affords some interesting phenomena in connection with the production of the stereoscopic effect. We have represented in Fig. 3 the manner of arranging the prisms.

Fig. 3.

Nachet Stereo-pseudoscopic Binocular.


NO. 1. NO. 2.

No. 1 displays the position of the prisms with reference to the objective when a stereoscopic effect is desired, and No. 2 the same when a pseudoscopic effect is produced.

In the first case, the rays from the left half of the cone proceeding from the objective, are totally reflected from the oblique surface of the prism (A), proceed horizontally to the oblique surface of the prism (B), are again totally reflected and emerge at the upper surface of the latter into the right hand body of the instrument. Those from the right half of the objective proceed direct from the objective through the prism (A) to the left hand body of the instrument. In this case the rays from the right and left half of the objective cross to the *left* and *right* eyes, respectively, of the observer, and give a true stereoscopic effect, while in the second arrangement, it will be noted that no such crossing of these rays is produced, and we obtain a pseudoscopic effect, or one in which the elevations appear as depressions and the depressions as elevations.

Dr. Carpenter states that *"The suddenness with which this conversion is brought about without any alteration in the position either of the object or the observer, but simply by a movement of the prism (A) is a phenomenon which no intelligent person can witness without interest; whilst it has a special value for those who study the physiology and psychology of binocular vision, and that the readiness with which the conversion is effected depends on the readiness of the mind to apprehend the converted forms."

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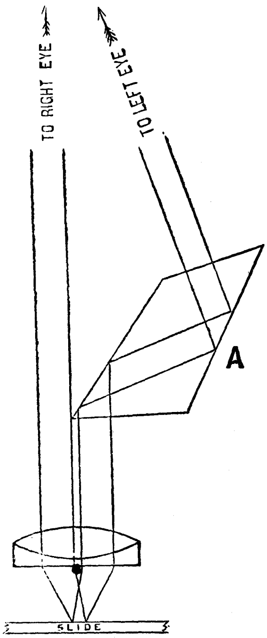
* The Microscope and its Revelations, 5th ed., p. 68.

To those who deny the production of a stereoscopic effect in this form of instrument, or in the other forms of stereoscopic binoculars, it will be difficult to explain the results obtained by the simple movement of the prism (A) in the Nachet form, as precisely similar effects are produced by the stereoscope, when the pictures intended for the different eyes are transposed,—in one case we obtain a stereoscopic and in the other a pseudoscopic effect.

Fig. 4.

Wenham Binocular.



The Wenham binocular, with which we are all familiar, can be described in a few words with the aid of Fig. 4. The rays from the left half of the objective proceed through the direct tube of the instrument to the right eye, while those from the right half suffer two internal total reflections in the prism (A) and from which the rays proceed up the lateral tube to the left eye. An additional advantage which the Wenham arrangement offers, over other forms of binoculars, is the simple arrangement by which it is converted into a monocular. The binocular prism placed in a sliding bar is capable of being moved in or out, each movement converting the instrument into a monocular or binocular as the case may be.

Objections, however, have been that we do not obtain as good results from this form of monocular, with the use of wide-angled lenses as with the single-tubed instrument. It may be that this claim is well founded, as the slides which support the binocular prism possibly do obstruct a portion of the peripheral rays proceeding from the posterior combination of the wide-angled lense. Furthermore, it has been urged that the diaphragm used in this form of binocular is in like manner detrimental when the instrument is used as a monocular. To meet these objections some makers provide an additional "nose-piece" which may be screwed on in place of the binocular arrangement, thus leaving the tube the full size of the ordinary monocular instrument.

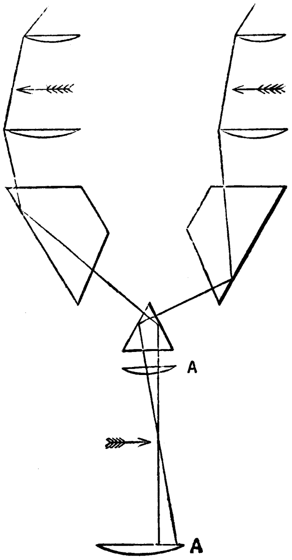


Fig. 5.
Tolles' Binocular Eye-Piece.

Tolles' Stereoscoptic Eye-piece (Fig. 5), consists in an arrangement of prisms after the Nachet plan, supplemented by an achromatic erecting eye-piece (which produces a secondary image of the object), the central prism being set so as to cause a division of the bundle of rays near the point of the crossing of the pencils in the eye-piece.

In the use of binoculars arranged on the Wenham, Nachet and Riddle plans, it is found* they do not give satisfactory results with powers above the ½ inch objective, as a rule, owing to the difficulty of approximating the prism which divides the cone of rays, to the posterior combination of lenses of high power.

Mr. Tolles overcomes these objections by using the erecting eye-piece and obtaining a secondary image. In referring to its advantages he says (Silliman's Journal, Vol. xxxix., p. 213): "When the binocular arrangement is embodied in the eye-piece, the prism being once fixed in proper position, as before described, is correctly placed for every power of objective, and the eye-piece, thus binocular in form, is as applicable through the whole range of powers as if it were monocular."

Our late President, H. L. Smith, spoke in glowing terms of the performance of the Tolles binocular, stating that the "Loss of light was trifling, easily remedied by a little more illumination, while the loss in defination was not so much as in the Wenham or Nachet forms." It is, however, expensive, which prevents its general adoption.

The argument urged against the Nachet arrangement of prisms, of loss of light, etc., should also be reasonably cited against the combination with the Tolles eye-piece. However, we must make great allowances for the perfect workmanship of the arrangement as made by Mr. Tolles, as he has, I am assured, obtained better results with his combination than other makers. Fig. 5 represents the Tolles arrangement (AA) being the erecting eye-piece which is attached to the ordinary monocular instrument while the prisms of the Nachet arrangement are seen in the upper part of the figure.

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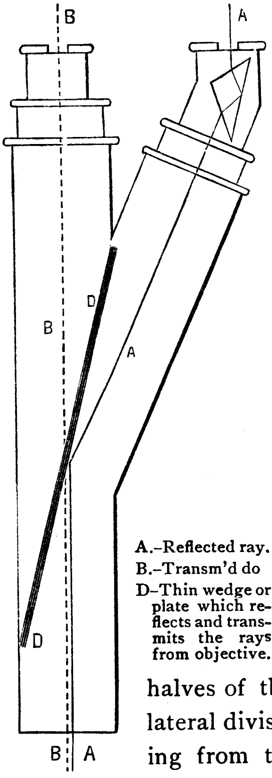
* It may be mentioned that very satisfactory results with comparatively high powers have been obtained even with the Wenham binocular. See Hon. J. D. Cox, Am. Jour. of Microscopy, Vol. iii., p. 56.

From the preceding *resumé* it appears that two different forms of binocular microscopes are constructed. Those improperly termed the non-stereoscopic, depending on the property of the double refraction of a ray of light when impinging upon the surface of a refractive prism at a suitable angle, as in the Powell & Lealand, Wenham non-stereoscopic, H. L. Smith (represented at Fig. 6), F. P. Barnard, and lastly the new stereoscopic ocular of Prof. E. Abbe (Fig. 7), which is a modification of the Powell & Lealand form, and in the arrangement of the prisms very similar to that proposed by Prof. F. P. Barnard in a paper read before the American Association for the Advancement of Science, 1870. Prof. Barnard's arrangement (Fig. 8) differed from that devised by Prof. Abbe in that the larger prism was made from a rectangular block of calc. spar.

Fig. 6.

Prof. H. L. Smith's Binocular Arrangement.

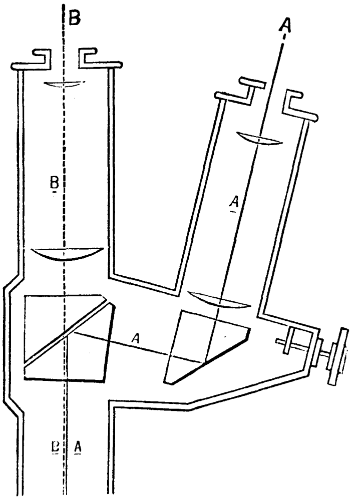


A.-Reflected ray.
B.-Transm'd do
D-Thin wedge or plate which reflects and transmits the rays from objective.

The principle upon which the stereoscopic binocular microscope is constructed (as before stated) depends upon the differences in the images produced by the lateral halves of the objective and usually consists in the bilateral division of the complete bundle of rays proceeding from the objective, and the presentation of each lateral pencil to the eyes of the observer so as to produce the stereoscopic effect. Prof. E. Abbe, whose stereoscopic ocular is represented at Fig. 7, obtains the stereoscopic effect by simply stopping off the apertures of the eye-pieces in such a manner as to present to each eye the image necessary to produce this impression. Dr. Carpenter, at the meeting of the Royal Microscopical Society, held

Fig. 7.

Abbe Binocular Eye-Piece.

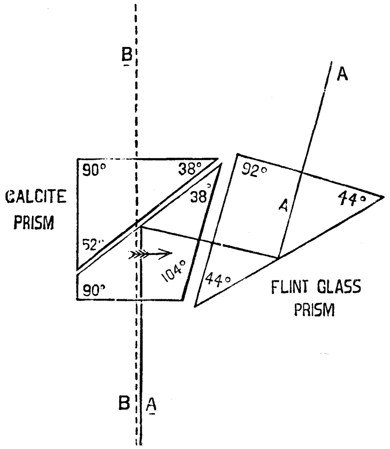


November 10, 1880, questions the possibility of a stereoscopic effect being produced in this manner. He is reported as saying, in referring to the eye-piece of Prof. Abbe, that "It seemed to him to have been overlooked that, in order to get a true stereoscopic projection, the rays from one side of the objective must cross completely over to the opposite side of the instrument. This was done in Nachet's and in Wenham's, and with either of these it was impossible to see an object in any other way than stereoscopically. To produce this effect it was necessary that the lateral inversion should be antagonized by the reflecting power of the prism—they must have the reflected ray crossing the other entirely, otherwise they could not have any stereoscopic effect. The mere fact that altering the caps (of the eye-piece) as described by Mr. Lettison was competent to change the instrument from stereoscopic to pseudoscopic, satisfied him at once that there was no true stereoscopic effect produced."

Dr. Carpenter, it appears to me, has overlooked the principal factor in the production of the stereoscopic effect with the microscope, in these remarks. Without a difference in the images produced by the different halves of the objective we could (*vide* previous remarks) not obtain a true stereoscopic effect (an effect of relief we do not consider). In the monocular instrument, for instance, we obtain an image of an object on the stage of the instrument with the complete bundle of rays focalizing at the eye-piece. With the *straight* tube of the Abbe eye-piece we would, with a similar object on the stage, have an image in every way identical with that produced by the monocular, excepting, perhaps, a slight loss of light by transmiscion. On comparing the image produced by the *lateral* tube or eye-piece of the Abbe arrangement with the two former, under similar conditions, we would unquestionably not be able to detect any difference except that occasioned by the *greater* loss of light in the latter instance. Theoretically the images produced by the different eye-pieces of the Abbe instrument should be exact duplicates in outline. Were it possible to construct perfect prisms and eye-pieces they would be so in reality (excepting difference of illumination.) They are produced by the rays from the same objective, the rays themselves being divided into a transmitted and reflected portion, thus producing images *similar* in outline. Now, if photographs of the images produced by the lateral halves of the eye-piece in these *three several instances* were taken, and two of them combined properly (i. e. the appropriate images) in the stereoscope, we should, if our premises are correct, obtain a true stereoscopic effect. Hence, by presenting the proper images (in the Abbe eye-piece) for stereoscopic vision, to the eyes of the observer, a true stereoscopic effect should be obtained. For similar reasons the Powell & Lealand and other arrangements, based on somewhat similar principles, should produce like results by the stoppage of the proper lateral rays of the different oculars.

Fig. 8.

Prof. Barnard's Binocular Arrangement.



Among the many recurring controversies to which present-day microscopists are subject, this one of superiority or non-superiority of the binocular arrangements over the monocular is not now often considered. It is desirable to understand the principles upon which their prominent qualities depend. Our inclinations in favor of the one or the other, within certain restrictions, will probably be governed by our early experience with the microscope. My observations would lead me to the belief that the individual who begins his career with a monocular, and has become accustomed to the use of one eye for observation (as is generally the case) seldom appreciates the stereoscope effect produced in the binocular arrangements, when the instrument, usually in the hands of others, is merely glanced through for a few moments at a time.

We are well aware that defective vision obliterates the effect produced by the stereoscope. I am *also* inclined to believe that a trifling temporary defect in the faculty of consentaneous focalization may be produced by the continued use of one eye with the monocular instrument, so that the microscopist who continually uses this instrument may be really incapacitated from realizing the advantage or effect of stereoscopic vision with the binocular form of instrument. My own personal experience with the two forms of instruments is, that after a continued use of the monocular " Acme " stand, it is sometime before my eyes become re-accustomed to the binocular, so as to enable me to appreciate fully the stereoscopic effect produced by it; while with a continued use of the binocular I experienced no such difficulty. Furthermore, I am disinclined to admit, as an objection to the converging-tube binoculars (the Wenham for instance), the argument that this convergance of the tubes is detrimental to the eye-sight in producing an unnatural straining of the lateral *reciti* muscles. In ordinary observation of objects at a distance of from ten to twelve inches from the eyes, the angle of convergance is very near that at which the Wenham instrument is used and should produce no more harm (on this account) than telescopic observations with the field-glass or that produced by the frequent and continued use of any optical instrument.